Morphological Evolution During Growth of InGaN Laser Diodes on Laterally Overgrown GaN on Sapphire

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The morphological evolution of InGaN laser diodes on lateral epitaxial overgrown GaN on sapphire was investigated to understand the affect of dislocations on the surface morphology and subsequently on device performance. InGaN-based laser diodes have potential in a number of applications such as optical storage, printing, full-color displays, chemical sensors and medical applications. Major developments in recent years have led to lifetimes in excess of 10,000 hours, demonstrating the viability of nitride laser diodes for commercial applications.[1] The implementations of lateral epitaxial overgrowth (LEO) and AlGaN/GaN modulation-doped strained-layer superlattices in the laser structure have led to increased lifetimes.[2] Strained-layer superlattices (SLSs) have been used for strain relief to prevent cracking in the cladding layers,[3] and the LEO technique has been shown to reduce the threading dislocation density in GaN grown by metalorganic chemical vapor deposition (MOCVD)[4-6] and hydride vapor phase epitaxy (HVPE).[7-8] This reduction in dislocation density from the LEO technique leads more efficient, lower threshold current density, longer lifetime lasers diodes.[1,9-10]

With a LEO GaN substrate, the effect of a single dislocation on the structural and electrical properties of the structure is magnified. The absence of dislocations in the LEO ‘wing’ regions significantly alters the surface morphology of a laser structure as compared to a laser structure grown on sapphire. The threading dislocations in LEO GaN on sapphire are predominantly located in ‘window’ stripes every 15 μm, whereas structures on sapphire substrates have a more uniform dislocation distribution over the wafer. The dislocation distribution dominates the size of features in the surface morphology. The structure for an InGaN laser diode on LEO GaN is shown in Figure 1. Atomic force microscopy (AFM) was used to investigate the surface morphology for lasers grown on LEO GaN and laser grown on sapphire, which was significantly different for the two structures. The lasers on sapphire show uniformly distributed small spirals whereas, on the LEO GaN the laser structure exhibits large spirals. Each of these spirals is formed around a threading dislocation with a screw component. These spirals grow in size until they meet another spiral. In the case of the LEO GaN, the threading dislocations are contained in the window region and are absent in the wing region. Thus the spirals one the laser of LEO GaN initiate in the window regions and can grow quite large over the wing until they meet another spiral from an adjacent window region forming a flat “trench-like” feature. In the case of the laser on sapphire, the spirals remain small because they meet neighboring spirals much more quickly due to the higher and more uniform dislocation distribution.

To investigate the origin and evolution of the spiraled surface morphology, a growth-interrupt series was performed on fully coalesced LEO GaN on sapphire. The laser structure was grown step-wise, interrupted at each major layer transition, since GaN, InGaN and AlGaN layers are typical grown under different reactor conditions and provide transitions of interest. The series consisted of four samples with growth terminated after the InGaN compliance layer, the n-AlGaN/GaN SLS cladding layer, the InGaN/InGaN:Si (multiple-quantum well) MQW active region, and after the p-AlGaN/GaN SLS cladding, as seen in Figure 2. Significant spiraling occurs during the growth of the active region due the high driving force conditions present in MOCVD reactor environment for InGaN growth. The spiral growth mode is strongly affected by the dislocation density and distribution in the structure. Spiral growth of the InGaN QWs may have an effect on well thickness fluctuations. The surface morphology for the n-cladding layer is fairly smooth, and the p-cladding smoothens the spiral initiated in the InGaN to a certain extent, but cannot recover surface morphology changes present prior to the active region. Cathodoluminescence (CL) and photoluminescence (PL) will be carried out to investigate the effect on spiral size and distribution on optical properties.

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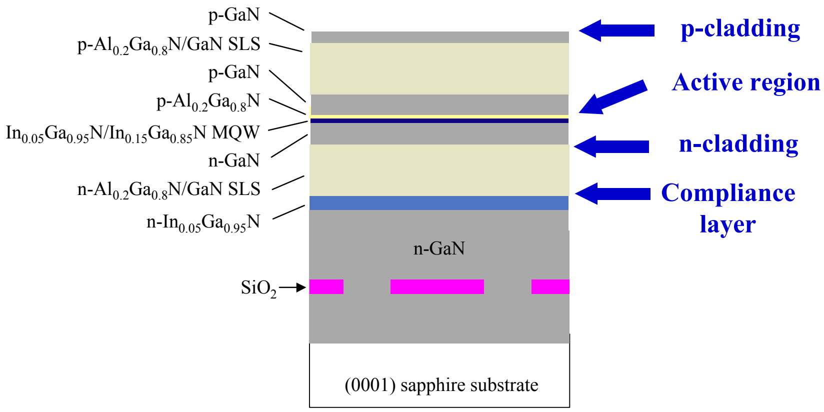

Figure 1: Laser structure on LEO GaN on sapphire. The growth interrupt locations are indicated by the arrows.

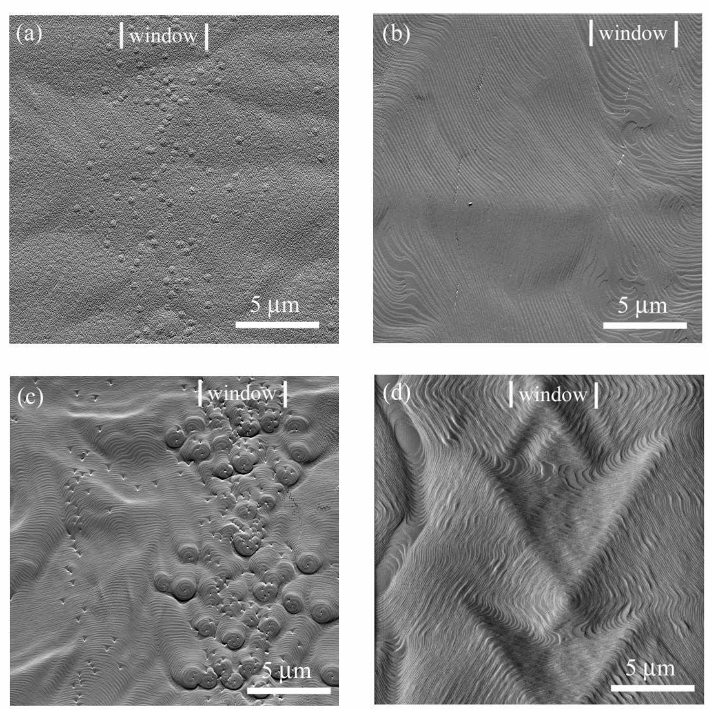

Figure 2: 20x20 μm^2 amplitude AFM images of the step-wise growth of the laser structure on LEO GaN. (a) InGaN compliance layer, (b) n-AlGaN/GaN SLS cladding, (c) InGaN/InGaN:Si MQW region, and (d) p- AlGaN/GaN SLS cladding. Note: The LEO stripes are running vertically.